Electricity is the flow of electric charge. The Greeks first observed electrical forces when early scientists rubbed amber with fur. The noticed they could attract small bits of straw with the amber. They called this the "amber effect". The Greek word for amber is "Elektron" and the effect was called "Elektrics", hence electricity.

Renaissance period

It was discovered that two objects rubbed by an identical third material would cause the two to experience a repulsive force. Conversely, if the two objects were rubbed by two different materials, an attractive force could be created. This is when the concept of two charge types, positive and negative, came about.

Ben Franklin: was credited to naming charges positive and negative. He believed electricity was a "fluid". Therefore, if a piece of amber was rubbed by fur, the fur would "absorb" this electric fluid, causing the amber to have a "deficit" of electric fluid, and hence a negative charge. His assumption turned out to be incorrect. In reality, electrons are deposited on to the amber from the fur. It is this reason by electrons were given a negative charge, simply because of an incorrect scientific assumption. An accident of history that has had a permanent impact on modern science and technology.

Fundamental Law of Charges

- Opposite charges attract
- Similar charges repel
- Charged objects attract some neutral objects

Basic structures of matter and their charges

- Electrons ($\bar{e}$) – negative charge $-1.6\times10^{-19}C$ or $-1e$
- Protons (p) – positive charge $1.6\times10^{-19}C$ or $1e$
- Neutrons (n) – neutral charge $0C$

__**Insulators**__: Do not allow the flow of electric charge (Rubber, air, most non-metallic substances)

__**Conductors**__: Do allow the flow of electric charge (Copper, aluminum, salt water, most metals)

__**Coulomb's Law**__

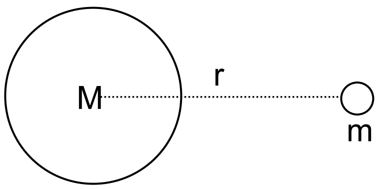
Charles Agustin de Coulomb (1736-1806) discovered the relationship between force and electric charge. He used a similar experiment to Newton's for determining the force of gravity.

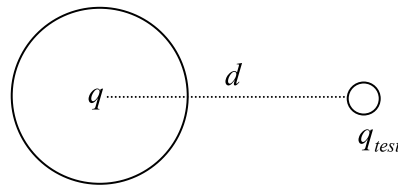
$$F_e = \frac{kq_1q_2}{d^2}$$

Where k is a constant with a value of $9.09\times10^{9}\frac{N\cdot m^2}{C^2}$ or $2.306\times10^{-28}\frac{N\cdot m^2}{e^2}$ and q_1 and q_2 are measured in Coulombs (C)

Electric Fields

Electric fields are analogous to gravitational fields. The **force of gravity** varies depending on the **mass** of the falling object yet the **acceleration** due to **gravity** is constant for all objects caught in the field.





$$F_g = \frac{GMm}{r^2}$$

$$\frac{F_g}{m} = \frac{GM}{r^2}$$

$$a_g = \frac{GM}{r^2}$$

a_g: Measure of gravitational field intensity.

$$F_e = \frac{kqq_{test}}{d^2}$$

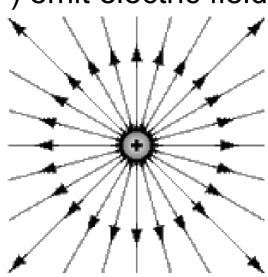
$$\frac{F_e}{q_{test}} = \frac{kq}{d^2}$$

$$\varepsilon = \frac{kq}{d^2}$$

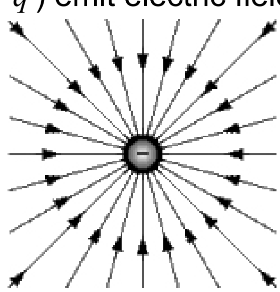
ε: Measure of electric field intensity.

Facts about electric fields

- The strength of an electric field is independent of the charge on the test charge q_{test}
- Positive charge sources (q) emit electric fields as lines of force, outward from the charge.



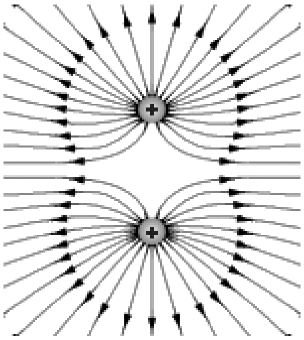
- Negative charge sources (-q) emit electric fields as lines of force, inward to the charge.

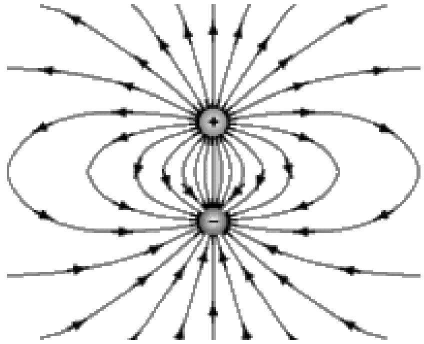


- Electric Fields are vector quantities

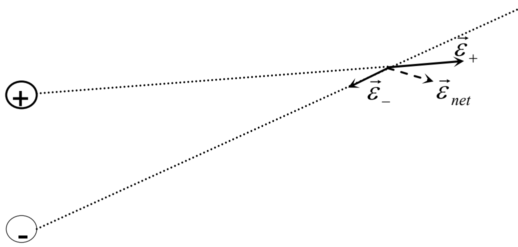
Electric Field Behaviour and Special Cases

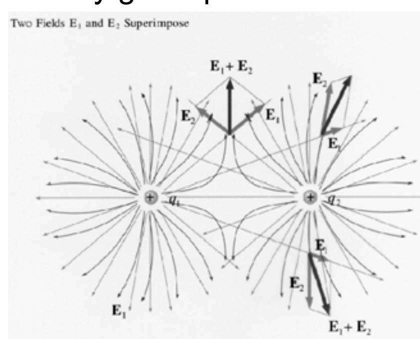
The behaviour of electric field lines are similar to that of magnetic field lines.





The above field lines represent the electric field at any given point.





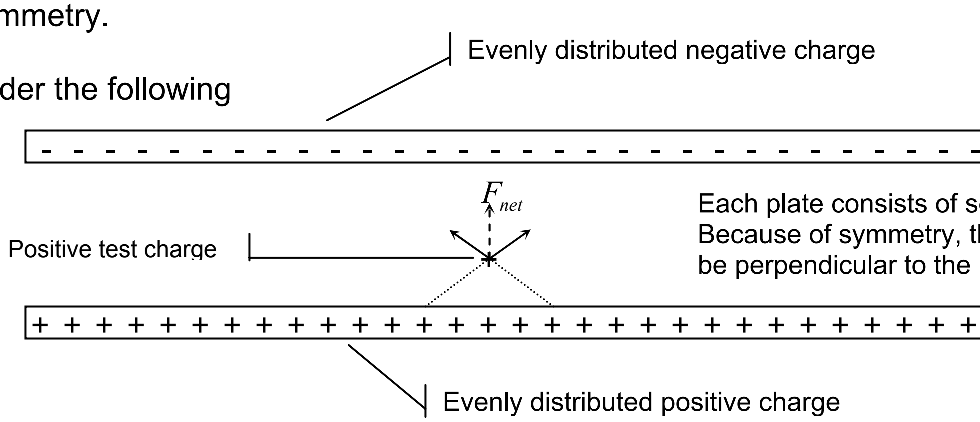
Special Case – Parallel Plates

In the case of the parallel plate, the field density remains constant between the two plates except at the edges. Therefore, $\vec{F}_e$ is constant between the plates. Parallel plates are used to accelerate charged particles. The electron gun of a television and computers monitors use parallel plate to accelerate a stream of electrons that cause the screen to illuminate.

Q: Why are the field lines parallel between the plates?

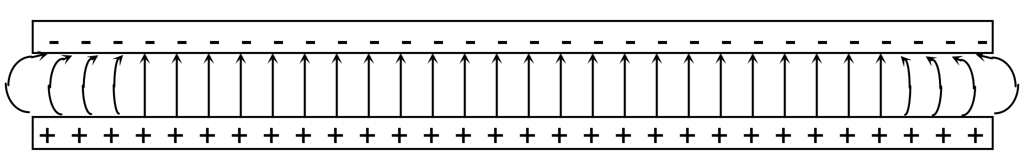
A: Symmetry.

Consider the following



Each plate consists of several point charges. Because of symmetry, the net force will always be perpendicular to the plate

The sum of F_e from **n** positive charges and **n** negative charges result in a F_{net} that is $\perp$ to the plate



Electric Potential Energy

As with gravity, there is a relationship between force and energy in electrostatics. Using an analogy argument between **gravity** and **electrostatics**

<table>
<tr>
<th><u>Gravity</u></th>
<th><u>Electrostatics</u></th>
</tr>
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<td>

$$F_g = \frac{GM_1M_2}{R^2}$$

Using integration, we can use the gravity equation to render the energy equation.

$$E_g = \int_R^{\infty} F_g dR$$

$$E_g = \frac{-GM_1M_2}{R}$$

Since gravity is an attractive force, gravitational potential energy is negative, implying objects are stuck in a potential well.

</td>
<td>

$$F_e = \frac{kq_1q_2}{d^2}$$

Using integration, we can use the gravity equation to render the energy equation.

$$E_e = \int_d^{\infty} F_e dd$$

$$E_e = \frac{kq_1q_2}{d}$$

Since electrostatic force can be an attractive or a repulsive force, electrostatic potential energy can be positive or negative, implying that **positive electrostatic potentials** mean that q_1 and q_2 are **like charges** (**repulsive** forces) and **negative electrostatic potentials** mean that q_1 and q_2 are **unlike** charges (**attractive** forces)

</td>
</tr>
</table>

Example: How much work is done on a proton, if it moved from a distance of 2.0m to infinity from a positive charge source of $3.0 \times 10^{-5} C$

E_e Vs. Voltage

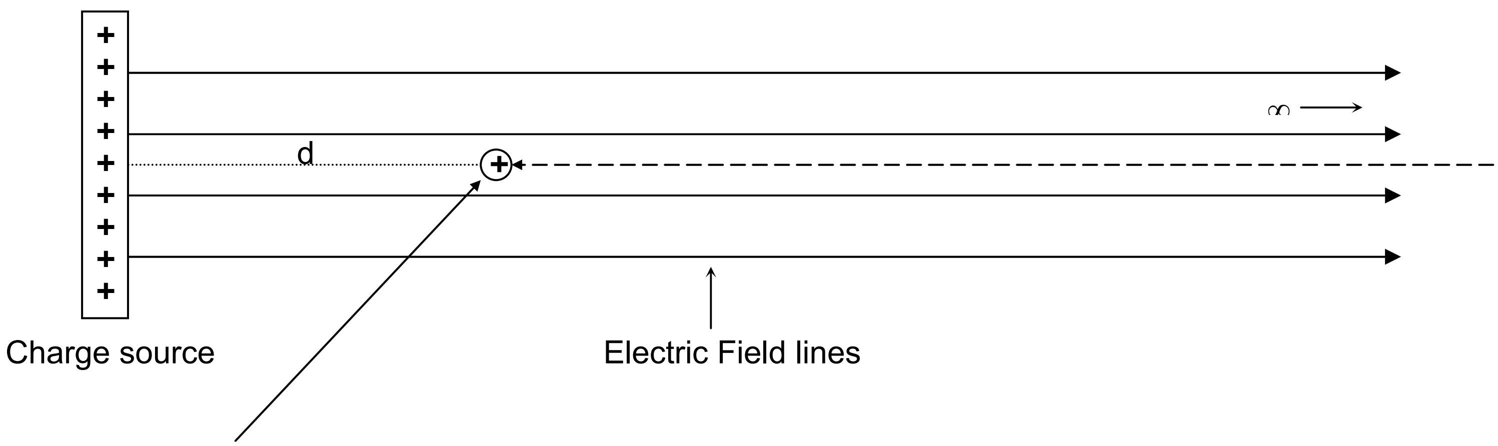
In electrostatics, the measure of electric potential is more commonly used than electric potential energy.

Electric potential is defined as follows:

$$\boxed{V = \frac{E_e}{q_{test}}}$$

Where E_e is the **absolute potential energy** in **Joules**, **V** is the **absolute electric potential** in **Volts**, and q_{test} is the charge on a positive test charge in **Coulombs**.

Note: The term absolute implies a measurement relative to infinity.

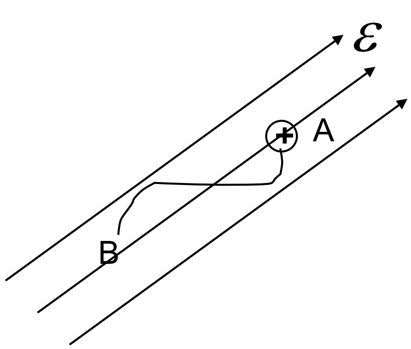


1 volt of electric potential measured at a point in space implies that it would take 1J of energy bring that charge from infinity to that point in space.

However, measurements from infinity are cumbersome and usually of little practical value. In general it is the differences in **electric potential** that are of concern.

I.E. Walking along a hallway at the 50th floor is no more dangerous than walking along the 1st floor, however falling down a flight of stairs from the 50th to the 49th floor is as dangerous as falling from the 1st floor to the basement.

Consider the following



Moving a positive test charge from point A to B.
Note: ΔE_e is independent of the path

E_e at A	E_e at B
$V = \frac{E_{e_A}}{q}$	$V = \frac{E_{e_B}}{q}$
$E_{e_A} = qV_A$	$E_{e_B} = qV_B$

$$\therefore \Delta E_e = qV_b - qV_A$$

$$\boxed{\Delta E_e = q\Delta V}$$

Amount of energy required to move a positive test charge (q_{test}) from A to B

Electrostatics and Work

Work is defined as a force through a distance or as a change of energy, or $W = F \cdot d$ and $W = \Delta E_e$, Therefore $\Delta E_e = F \cdot d$.

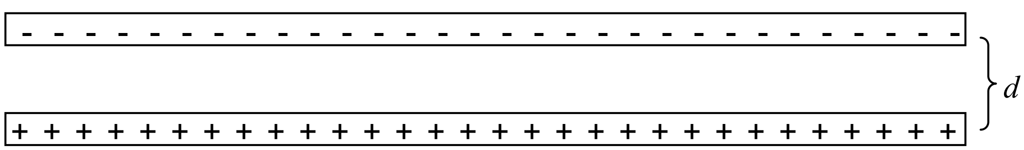
Furthermore $\Delta E_e = q\Delta V$ and $\varepsilon = \frac{F_e}{q}$

$$\Delta E_e = F_e \cdot d$$
$$q\Delta V = F_e \cdot d$$
$$\Delta V = \frac{F_e}{q} \cdot d$$
$$\frac{\Delta V}{d} = \frac{F_e}{q}$$
$$\frac{\Delta V}{d} = \varepsilon$$

$$\boxed{\varepsilon = \frac{\Delta V}{d}}$$

Special Cases- The parallel plate

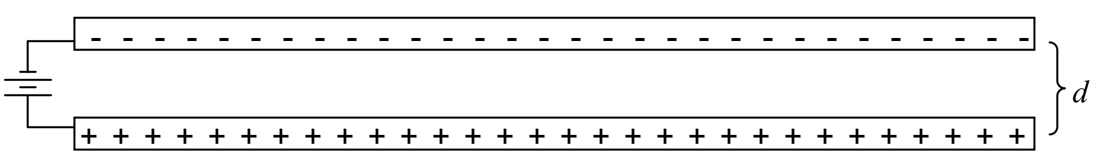
First case: Two charged parallel plates



The two parallel plates have a fixed amount of charge on each. As discussed earlier, the electric field between two parallel plates is constant no matter where a charge is located between the plates (excluding the edges of course). This also implies that the field strength between the two plates is independent of the plate separation (remember, the charge on each plate is constant).

Based on the equation above, $\varepsilon = \frac{\Delta V}{d}$, as the separation increases between the plates, the voltage must increase between the plates in order to maintain a constant electric field.

Second case: Two charged parallel plates, attached to a fixed voltage supply



In this case the voltage is fixed, therefore according to the formula $\varepsilon = \frac{\Delta V}{d}$, as the distance increases, the electric field strength must decrease and as the distance decreases, the electric field strength must increase. Note: the amount charge on each plate is not fixed in this case. As the plates get closer, the force of electrostatic attraction increases, inducing more electrons from the power supply to collect on the negative plate and more electrons to recede from the positive plate to the positive side of the power supply.

Questions:

1. Two point charges, $-2.0\times10^{-5}C$ and $4.0\times10^{-5}C$ respectively, are separated by 10cm find
   a) The electric potential energy stored in the two charges
   b) The electric force between the two charges.

2. Find the voltage and the electric field created by a $4.0\times10^{-5}C$ from a distance of
   a) 2.0m
   b) 4.0m

3. Two charged parallel plates are separated by a distance of 2.0cm. The voltage between the two plates is 500V. Find
   a) The electric field strength between the two plates
   b) Assuming the plates are no longer attached to a power supply, find the electric field strength between the plates if the distance is doubled.
   c) Assuming the plates are no longer attached to a power supply, find the voltage between the plates if the distance is doubled.

4. Two parallel plates are attached to a 1000V power supply. If the plates are separated by a distance of 5.0cm, find
   a) the speed at which and electron will arrive at the positive plate ($m_e = 9.1\times10^{-31}kg$)
   b) the speed at which a proton would arrive at the negative plate ($m_p = 1.67\times10^{-27}kg$)
   c) calculate a) and b) if the distance between the two plates is doubled.

5. Using a parallel plate apparatus, find the voltage required to balance a $1.0\times10^{-5}kg$ dust particle if the dust particle has a charge of $2.0\times10^{-6}C$ and the plates are separated by 5.0cm.